Report No. RD-65-122

PB169149

AD650833

FINAL REPORT

Project No. 241-004-01V

EVALUATION OF SFD-315 MAGNETRON AND SOLID STATE DUPLEXER FOR ASDE-2

OCTOBER 1965

FEDERAL AVIATION AGENCY
Systems Research & Development Service
Atlantic City, New Jersey

57

FINAL REPORT

EVALUATION OF SFD-315 MAGNETRON AND SOLID STATE DUPLEXER FOR ASDE-2

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Prepared by:

WOODROW R. APPLEGATE

OCTOBER 1965

This report has been approved for general availability. It does not necessarily reflect FAA policy in all respects and it does not, in itself, constitute a standard, specification, or regulation.

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57

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

Test and Evaluation Division, Systems Research and Development Service
Federal Aviation Agency, Atlantic City, New Jersey
EVALUATION OF SFD-315 MAGNETRON AND SOLID STATE DUPLEXER FOR ASDE-2
by W. Applegate, October 1965
49 pp., inc. 13 illus., plus 4 appendixes (12 pp.) Final Report
(Project No. 241-004-01V, Report No. RD-65-122

ABSTRACT

Evaluation of an Inverted Circular Electric Mode (ICEM) Coaxial Magnetron and a Solid State Duplexer was undertaken by the Federal Aviation Agency (FAA) at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, New Jersey, to determine their suitability as replacements for corresponding components originally incorporated in Airport Surface Detection Equipment (ASDE-2). The Department of the Army accomplished the development of the new components under contract on behalf of the FAA.

The report describes the SFD-315 magnetron and the Solid State Duplexer and presents the results of various tests conducted to appraise their performance. The ASDE-2 at NAFEC was equipped with specially modified modulators for tests of the SFD-315 magnetron. The Solid State Duplexer was operated in an unmodified channel of the radar and performed satisfactorily throughout a life-test period of 2500 hours.

It was concluded that satisfactory system performance can not be achieved using the modified modulators provided for operation of the SFD-315 magnetron; however, the SFD-315 magnetron is suitable for ASDE-2 applications with a compatible modulator, and may be expected to operate satisfactorily for more than 5000 hours. It was also concluded that the Solid State Duplexer is a suitable replacement for the original duplexer of ASDE-2.

It was recommended that the SFD-315 magnetron not be adopted as a direct replacement for existing ASDE-2 magnetrons but that the Solid State Duplexer be adopted by the FAA as a replacement duplexer for operational ASDE-2 equipments. It was further recommended that procurement specifications for future K-band ASDE radars provide for application of the SFD-315 magnetron or equivalent ICEM type, incorporation of a compatible modulator and a Solid State Duplexer.

INTRODUCTION

Purpose

The purpose of this project was to evaluate new K-band radar components, including an Inverted Circular Electric Mode (ICEM) Coaxial Magnetron and a Solid State Duplexer, in order to determine their suitability, with respect to performance and operating life, for use in the Airport Surface Detection Equipment, Model ASDE-2, of the Federal Aviation Agency.

Background

As part of a Federal Aviation Agency (FAA) program for improving the effectiveness of Airport Surface Detection Equipment (ASDE-2), development of various modifications was undertaken. A rigid K-band radome was developed under Contract FAA/SRDS-493.[1] Figure 1 shows the ASDE-2 at the National Aviation Facilities Experimental Center (NAFEC), Atlantic City, N. J. during installation of the radome which had been supplied by Goodyear Aircraft Corporation, Akron, Ohio. In addition, the Systems Research and Development Service (SRDS) of the FAA arranged, through the Department of the Army, for development of a magnetron to replace the BOMAC BL-M006 magnetron, whose operating life had been found unsatisfactory, and for the development of a replacement for the duplexer which had not given adequate protection to receiver crystals.

The development of a new magnetron was undertaken by S-F-D Laboratories, Inc., Union, New Jersey, under Department of the Army Contract No. DA36-039-SC87347. The contract provided not only for development of the magnetron but also for compatible mechanical and electrical modifications to the existing ASDE-2 modulator, or other suitable demonstration that the new magnetron could satisfy ASDE-2 requirements. The salient specifications for the magnetron, as extracted from the Signal Corps Technical Requirements, SLC-7001/57B, dated March 6, 1961, are summarized in Appendix I.

The cathode structure of the Inverted Circular Electric Mode (ICEM) magnetron was an annular ring which encircled the resonator cavity and the anode. This arrangement was designed to provide a cathode surface

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[1]Final Report, Project No. 107-103V, Evaluation of Rigid Radome of the Airport Surface Detection Equipment (ASDE) Radar, Evaluation Division, Systems Research and Development Service, FAA, Atlantic City, N.J. February 1963.

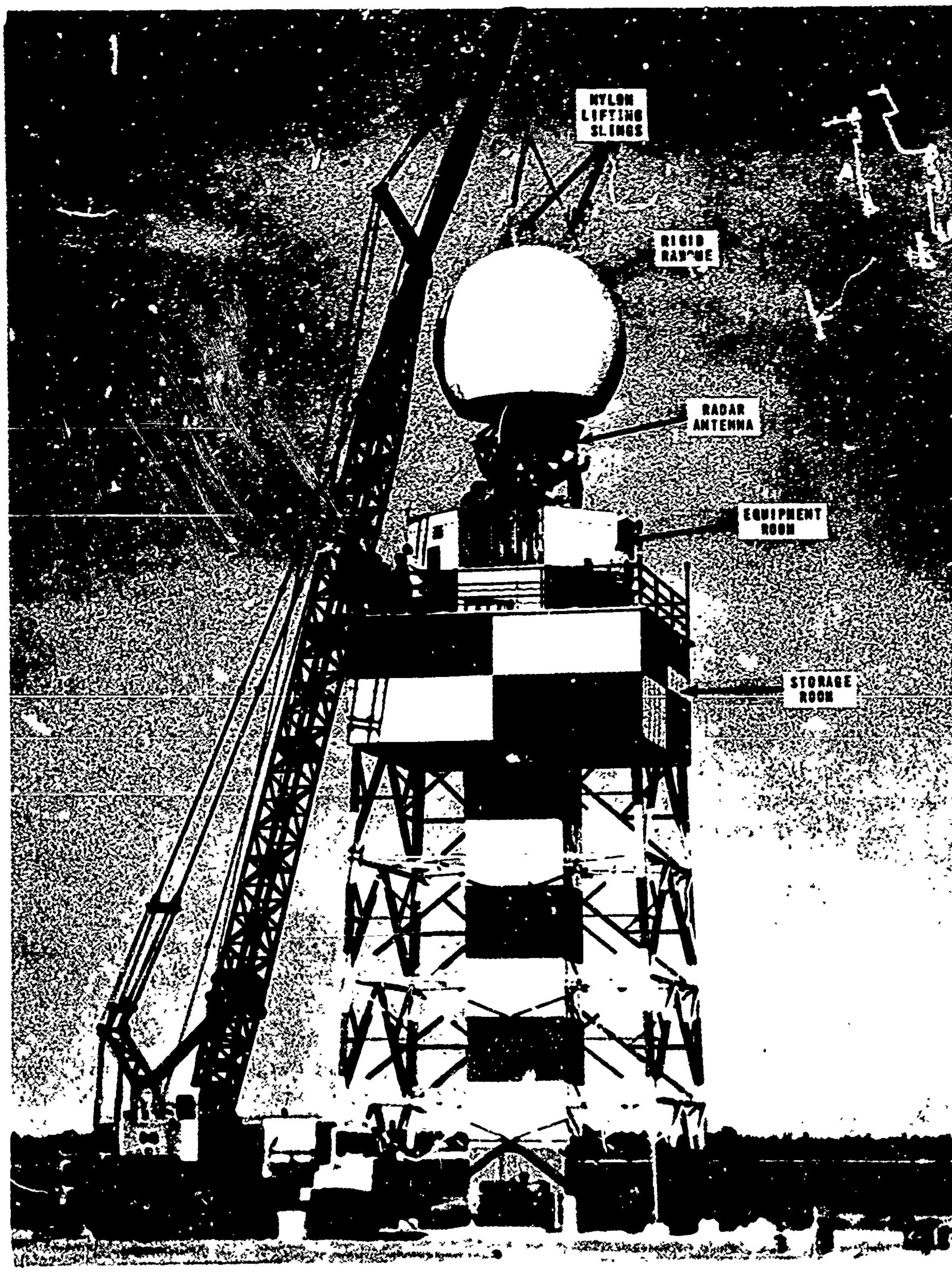

FIG. 1 RIGID RADOME BEING INSTALLED IN AIRPORT SURFACE DETECTION EQUIPMENT, ASDE-2

greater than the BOMAC Type BL-M006 magnetron where the cathode is at the center of the resonator configuration. Due to the greater cathode surface area, the ICEM magnetron was expected to be less likely to suffer cathode failure. Five of the new magnetrons, designated SFD-315, were delivered for tests. Four of these were life tested in laboratory modulators at the contractor's plant and another in the ASDE-2 test bed facility at NAFEC. Physical dimensions, mounting provisions and electrical characteristics of the new magnetron had prevented direct interchangeability with the BL-M006 magnetron. Figure 2 shows the SFD-315 magnetron and modified modulator as installed in Channel B of the NAFEC ASDE-2 by S-F-D and NAFEC personnel. The original modulator modifications are described in the technical reports prepared by the contractor and summarized in a final technical report issued in June 1964.[2] In Figure 3, enlarged views are presented for a comparison of the mounting provisions for SFD-315 and BL-M006 types of magnetron.

An interim report of the magnetron tests at NAFEC was prepared in May 1964.[3] Although the duration of pulses delivered by this modulator-magnetron combination was not short enough to fall within system specifications, the magnetron operated for 4200 hours. Appendix II contains a summary of the interpretations made by S-F-D regarding the performance of the SFD-315 magnetron in the modulator modified for the ASDE-2 at NAFEC.

The airborne Instrument Laboratories (AIL), Inc., Long Island, New York, undertook to reduce the magnetron's pulse duration by remodifying the modulator under Contract FA-64-5159. After it was modified by AIL, the modulator was reinstalled in Channel B of the NAFEC ASDE-2 for completion of the remaining life tests. Changes incorporated in the modulator by AIL are described in Appendix III.

Two Solid State Duplexers were delivered by Microwave Associates, (MAI), Inc., Burlington, Massachusettes, under Department of the Army Contract, DA-36-039-SC-90834.

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[2]Final Technical Report, SFD Report No. 16-F, Research and Development Long Life K-Band Coaxial Magnetron, S-F-D Laboratories, Inc., Union, New Jersey, June 1964.

[3]Interim Report, Project No. 107-001-01V, Evaluation of SFD-315 Magnetron for ASDE-2 Evaluation Division Systems Research and Development Service, FAA, Atlantic City, New Jersey, May 1964.

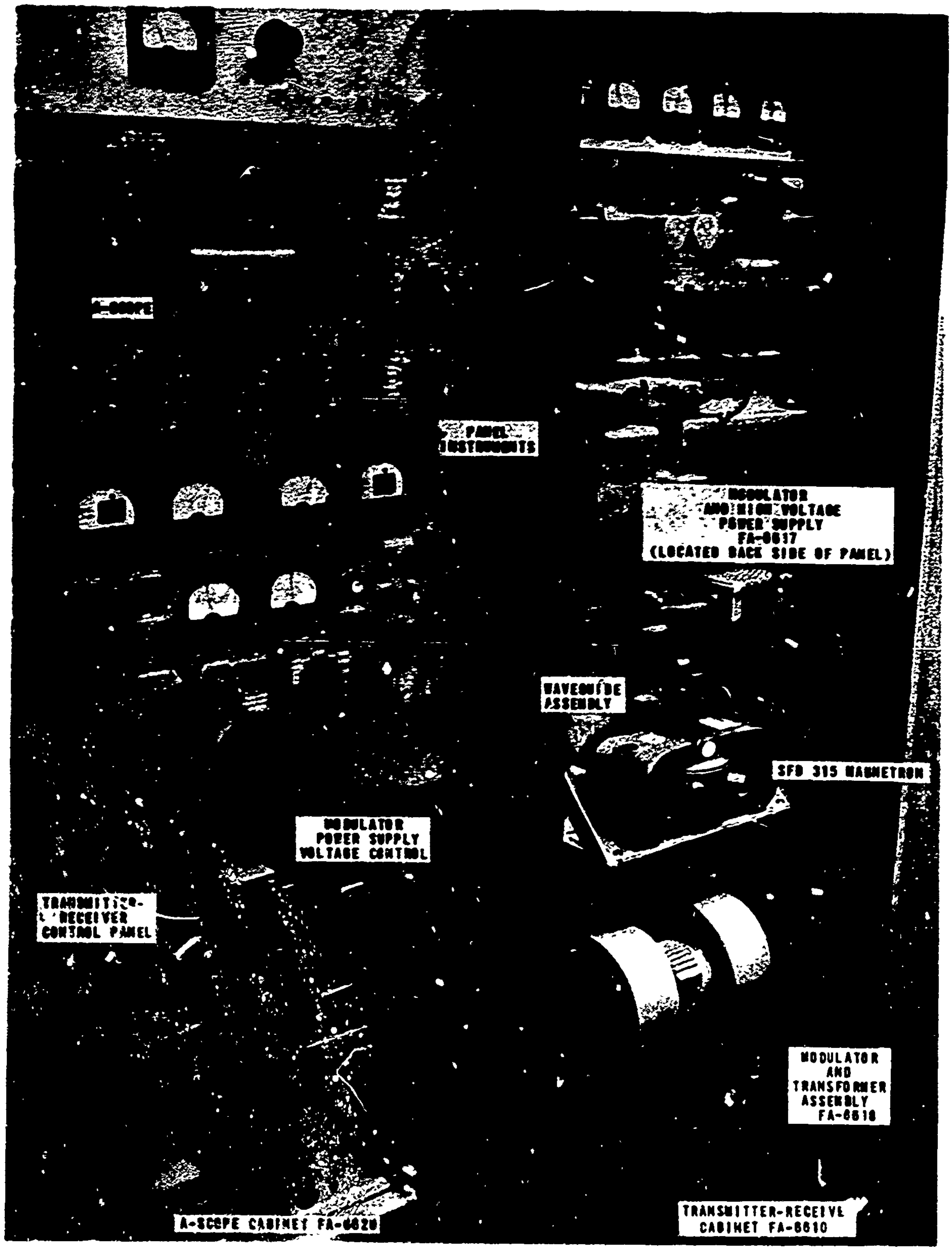
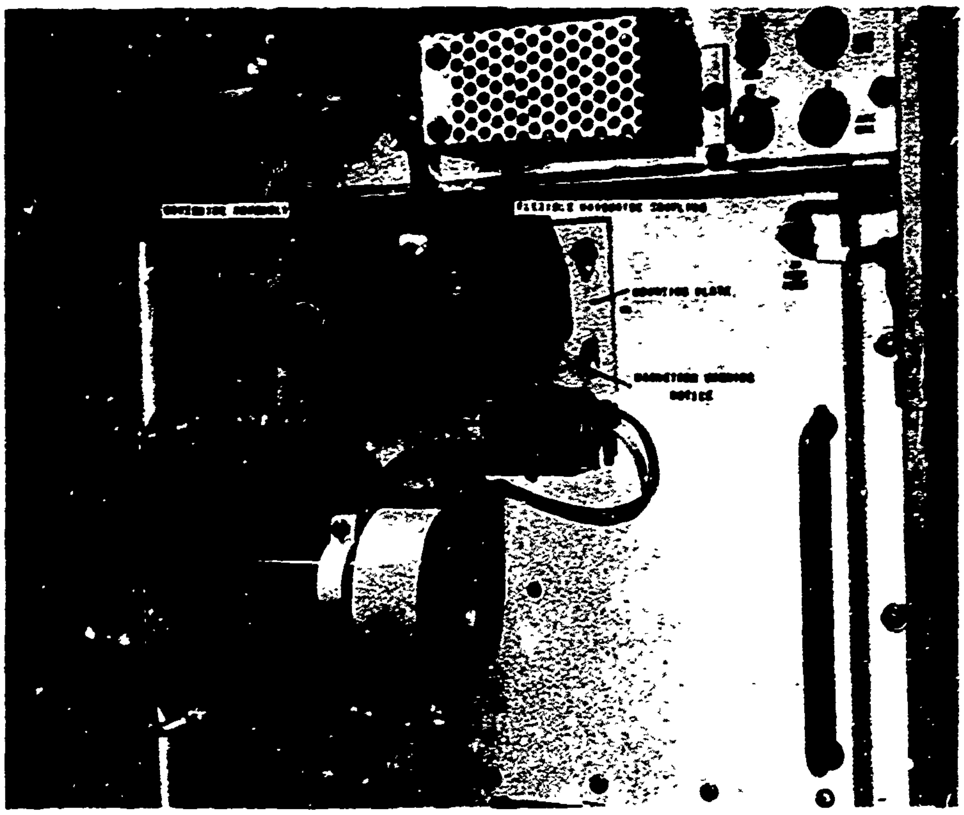
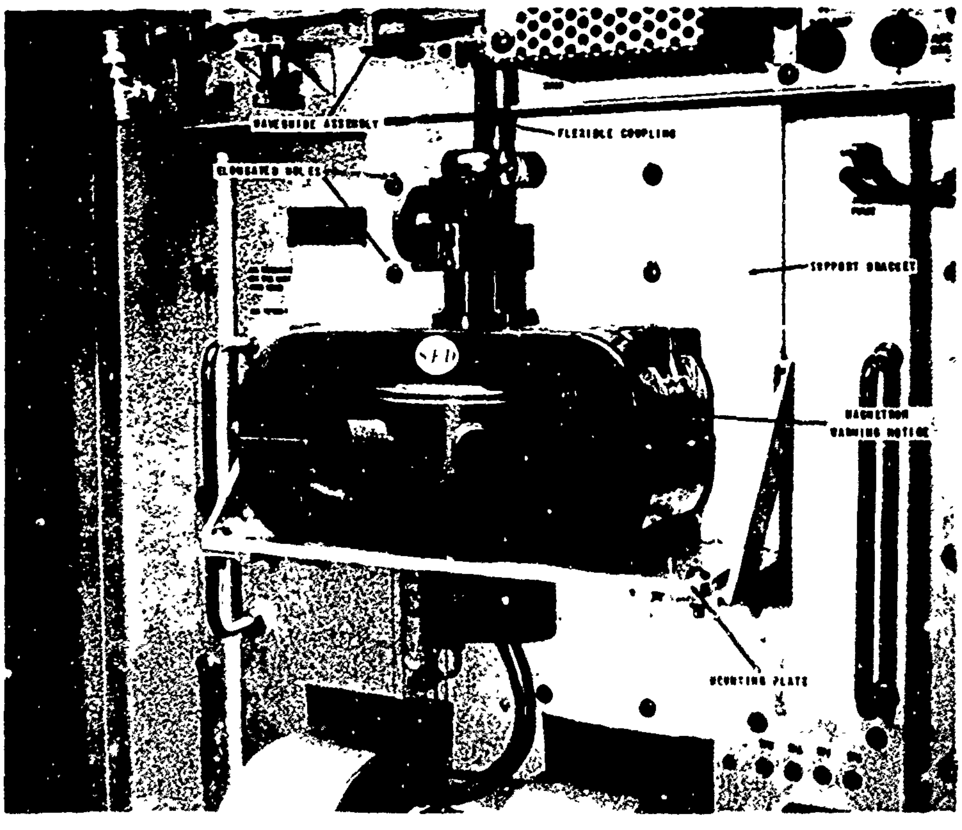


FIG. 2 A-SCOPE CABINET FA-6620 AND TRANSMITTER-RECEIVER CABINET FA-6610 OF CHANNEL B IN ASDE-2 WITH CABINET DOORS REMOVED



a. BL-M006 MAGNETRON



b. SFD-315 MAGNETRON

FIG. 3 MOUNTING OF BL-M006 MAGNETRON AND SFD-315 MAGNETRON

This duplexer was developed to enhance receiver-crystal life and to improve system performance at minimum ranges by incorporating an improved gas-type transmit-receive (TR) tube, a ferrite circulator and a semi-conductor (varactor) limiter. It was designed to have a life expectancy of 5000 hours and be physically and electrically interchangeable with the original duplexer.[4] Both types are illustrated in Figure 4, as installed in the ASDE-2 at NAFEC.

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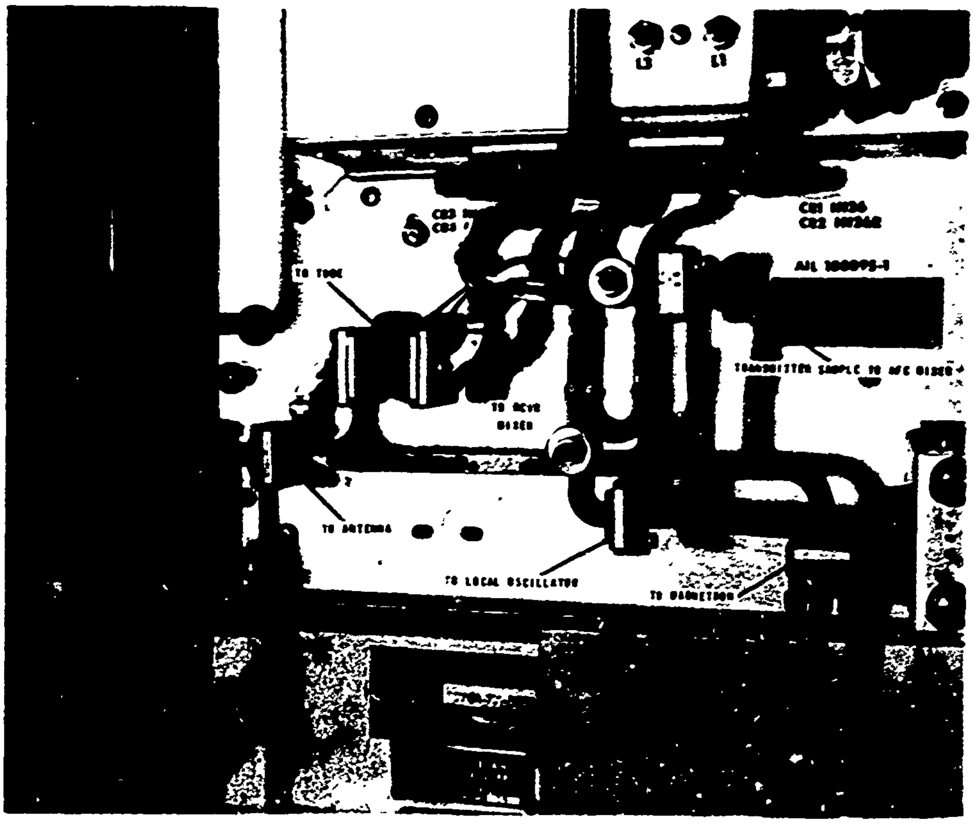
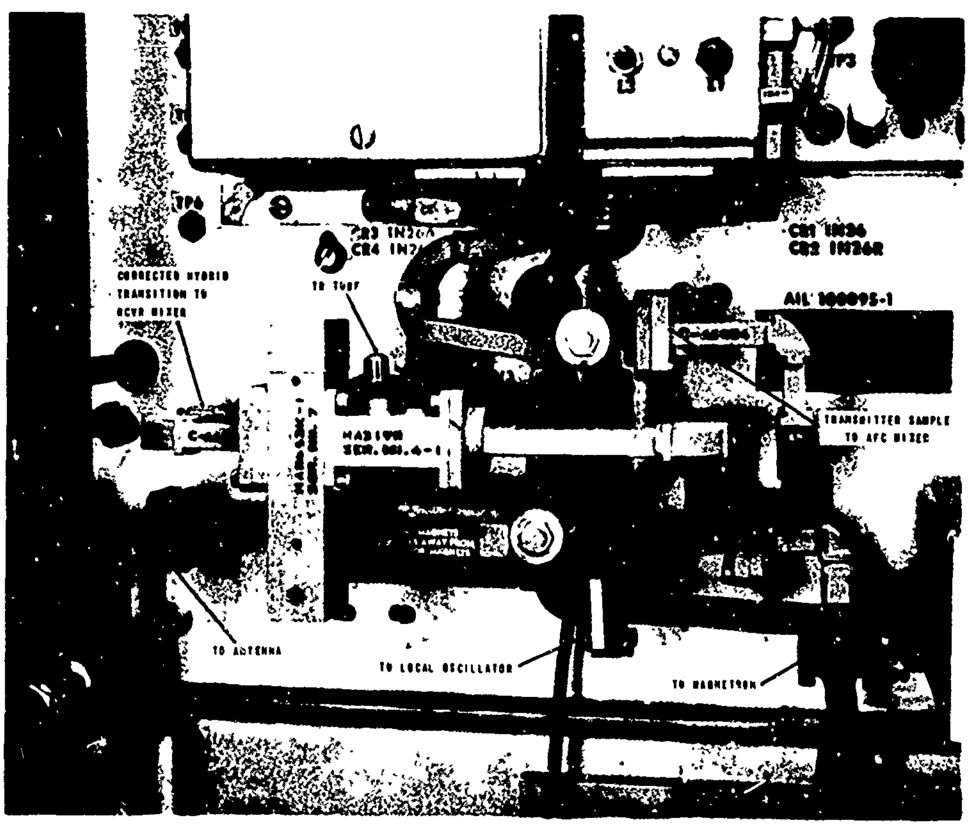
[4]The TR tube of the Solid State Duplexer operated at a lower keep-alive voltage than supplied by ASDE-2 for the original duplexer.



a. STANDARD DUPLEXER



b. SOLID STATE DUPLEXER

FIG. 4 INSTALLATION OF STANDARD DUPLEXER AND SOLID STATE DUPLEXER IN CHANNEL A

DISCUSSION

Test Procedures and Results

General

The ASDE-2 was designed as a dual channel radar system to assure high operational reliability. In the event of failure of the operating channel (A), operation could be transferred to the standby channel (B), by remote control.

The Solid State Duplexer, as delivered by MAI, was life tested in Channel A where it was substituted for the original duplexer and where it was operated together with the standard modulator, transmitter, antenna and receiver system as normally configured in ASDE-2. The SFD-315 magnetron, which was not electrically and mechanically interchangeable with the BL-M006 magnetron of the original system, was life tested in Channel B. The rigid radome was installed on the ASDE-2 throughout the test program. Voltage Standing Wave Ratio (VSWR), was measured before testing for magnetron operation; a Polarad K-band signal generator and 1000 c/s square wave generator Model G2225-1 were employed for VSWR tests.

In order to establish performance levels as controls for the testing of new components in the ASDE-2, Channel A was aligned and adjusted for optimum performance, in accordance with prescribed procedures, and the system operating parameters observed in terms of standard instrument readings. Observations were repeated when verifications were required throughout the life test and when technical tests of the new components were performed.

The alignment was accomplished in accordance with the recommended procedures described in the instruction manual,[5] and the current FAA maintenance handbook[6] for ASDE-2. Typical operating levels of the ASDE-2 parameters, with the BL-M006 magnetron are listed in Table I. Table II presents the schedules of specific measurements and panel instrument observations taken during the life tests.

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[5]Instruction Book, Airport Surface Detection Equipment, Model ASDE-2, Type FA-6600, Volume I, (Sections 1-9), Airborne Instruments Laboratory, Inc., Deer Park, Long Island, New York, November 1961.

[6]FAA Handbook, SMP6330.1, Maintenance of Airport Surface Detection Equipment (ASDE) Facilities, FAA, Washington, D. C., December 7, 1964.

TABLE I

TYPICAL OPERATING CONDITIONS FOR ASDE-2 AT NAFEC

	Operating Parameter	Operating Level
1.	Transmitter Frequency, Gc/s	24.1
2.	Pulse Duration, ns	20
3.	Pulse Repetition Rate, pulses/s	14,440
4.	Average Power, W	10.25
5.	Magnetron Current, mA	4.0
6.	Modulator High Voltage, kV	13.75
7.	Modulator Current, mA	16.50
8.	Voltage Standing Wave Ratio, VSWR	1:15:1
9.	Receiver Crystal Current No. 1, uA	400
10.	Receiver Crystal Current No. 2, uA	450
11.	AFC Crystal Current No. 3, uA	450
12.	AFC Crystal Current No. 4, uA	450
13.	Keep-Alive Current, uA	375
14.	Receiver Sensitivity, dBm	-80
15.	Receiver Noise Figure, dB	17.0
16.	Minimum Range	5/8" measured on scope "A" range; 175 Ft. on airport surface

TABLE II

OBSERVATION SCHEDULE FOR MONITORING ASDE-2 OPERATION

Observation	Interval
Transmitter RF Output Pulse Characteristics	Start of test and each 1000 Hrs. during operating life
VSWR	Start of test and each 250 Hrs. during operating life
Transmitter Frequency	ditto
Transmitter Average Power Output	ditto
Pulse Repitition Rate	ditto
Transmitter-Receiver Recovery Time	ditto
Magnetron Current	Daily
Modulator Current	Daily
Modulator High Voltage	Daily
Receiver Noise Figure	Start of tests and each 250 Hrs. during operating life
Receiver Sensitivity	ditto
Receiver Crystal Current #1	Daily
Receiver Crystal Current #2	Daily
Receiver Crystal Current #3	Daily
Receiver Crystal Current #4	Daily
TR Tube Keep-Alive Current	Daily
Observation of Video Display	Daily
Minimum Range	During first 500 Hrs. of life testing

The first magnetron which arrived at NAFEC, Serial No. E17E, developed a malfunction after a brief period of operation; it was returned to the manufacturer. The second magnetron, Serial No. G12E, was operated throughout the test period; all performance and life test data were obtained with the second magnetron. Four of the magnetrons previously life tested at the manufacturer's plant in special laboratory modulators, were also operated briefly at NAFEC to determine their consistency with Serial No. G12E.

Tests of SFD-315 Magnetron: Performance of the SFD-315 magnetron was evaluated by comparison with the performance obtainable with the BL-M006 magnetron. Operating frequency, stability, peak power, pulse shape, pulse duration of the magnetron output, as delivered to the RF sections of the radar system, were all examined with respect to compatibility with ASDE-2 performance requirements. Throughout the tests, magnetron current was held at 4.0 mA by adjustment of the high voltage supplied to the modulator.

Table III lists the manufacturer's recommended operating conditions for the particular magnetron with which the life tests were accomplished at NAFEC.

Two sets of comparative data were obtained because the ASDE-2 modulator was configured in two different ways during the project. Observations of panel instruments, measurement of operating frequency and computation of peak pulse power generally produced consistent results. The first set of data, listed in Table IV, shows how various operating conditions for the BL-M006 magnetron in Channel A compared during the early testing with the operating conditions for the SFD-315 magnetron in Channel B where the modulator had been modified by S-F-D.

The results described below were obtained during overlapping time periods when both the SFD-315 magnetron and the Solid State Duplexer often operated concurrently.

Panel Instrument Observations - The ASDE-2 panel instruments were frequently observed to insure that the electrical levels for the SFD-315 magnetron were being maintained within the limits established by the manufacturer.

Once the equipment was adjusted to the chosen operating conditions for a test, panel instrument readings were recorded and monitored regularly. Generally, stable operation was experienced except when malfunctions occurred in the radar. Panel instrument observations, therefore, served primarily to identify impending malfunctions and to establish whether system operation was within prescribed tolerances.

TABLE III

MANUFACTURER'S RECOMMENDED OPERATING CONDITIONS

FOR THE SFD-315 MAGNETRON, SERIAL NO. G12E

	Operating Parameter	Operating Level
1.	Transmitter Frequency, Gc/s	24.13
2.	Pulse Duration, ns	20
3.	Power Output (Average), W	15.2
4.	Power Output (Peak), kW	50.3
5.	Magnetron Current, mA	4.0
6.	Modulator High Voltage, kV	13.5
7.	Filament Voltage, V	14.5
8.	Filament Current, A	5.0
9.	Duty Cycle	.0003

TABLE IV

OPERATING CONDITIONS ESTABLISHED IN ASDE-2
DURING EARLY PHASE OF MAGNETRON LIFE TEST WITH
S-F-D MODULATOR MODIFICATIONS

BL-M006 Operation in Unmodified Channel A
SFD-315 Operation in Channel B Modified by S-F-D

Operating Parameter	BL-M006 Magnetron in Channel A	SFD-315 Magnetron in Channel B
Transmitter Frequency, Gc/s	24.0	24.1
Pulse Duration, ns	20.0	40.0
Rise Time, ns	4.0	10.0
Decay Time, ns	10.0	30+
Pulse Repetition Rate, pulses/s	14,400	14,400
Average Power, W	12.5	13.4
Peak Power, kW	43.1	23.1
Magnetron Current, mA	4.0	4.0
Modulator High Voltage, kV	13.5	15.0
Modulator Current, mA	16.0	16.5
Voltage Standing Wave Ratio	1.24/1	1.10/1
Duty Cycle	0.00029	0.00058

Frequency Measurements - The operating frequency of the SFD-315 Magnetron, Serial No. G12E, checked periodically with a Hewlett Packard Frequency Meter Model K-532A, remained stable at 24.1 Gc/s throughout the test program.

Power Measurements - Average radar power measurements for the SFD-315 magnetron were accomplished with a Sperry Microline RF Power Bridge, Model 31A1, and test equipment normally supplied at the ASDE-2 radar site. Peak power output levels were derived by calculations utilizing the measured average power reading and duty cycle based on observed pulse duration.

Average power deliverd by the SFD-315 magnetron generally exceeded the average power available from BL-M006 magnetrons by several watts. However, due to distortion of pulse shape, the calculated peak power was at least 20% lower than the peak power obtained from the BL-M006 magnetron.

Pulse Measurements - The RF output pulse delivered by the transmitter was sampled, detected and displayed on a Hewlett Packard Oscilloscope, Model 185B, where the rise time, fall time, pulse duration and any peculiarities of pulse shape were observed. After calibration of the oscilloscope by the manufacturer, the horizontal sweep time scale was periodically recalibrated using the self-contained 50 Mc/s standard oscillator. With the oscilloscope adjusted to a linear sweep rate of 10 nanoseconds per centimeter, photographs of the transmitter pulse shape were obtained. The sampling was accomplished with a tuned K-band crystal detector installed near the RF switch in the ASDE-2 waveguide system. Observed pulse characteristics were compared frequently with like observations of the characteristics of pulses from the BL-M006 magnetron.

Rise time of the SFD-315 magnetron output pulse was originally observed to be about 10 ns, decay time was more than about 30 ns, and pulse duration at the half power level was more than 40 ns. These values exceeded allowable limits for the ASDE-2 system. Figure 5 shows how the shape of the pulses delivered by the SFD-315 magnetron in Channel B compared with pulses delivered by the BL-M006 magnetron in Channel A.

A number of changes were incorporated by S-F-D Laboratories in the modulator after its installation in the NAFEC ASDE-2; however, the transmitter-pulse duration continued to exceed 40 ns, whereas the radar specification provided that the transmitter pulse should be 20 $\pm$ ns. Some of these changes altered the transmitter pulse but none were successful in producing a pulse comparable to that of Channel A.

BL-MOO6 MAGNETRON IN CHANNEL A (UNMODIFIED)

SFD-315 MAGNETRON IN CHANNEL B (AS MODIFIED BY S-F-D)

FIG. 5 TYPICAL WAVEFORMS REPRESENTING TRANSMITTER OUTPUT-PULSES PRODUCED BY CHANNELS A AND B DURING INITIAL PERFORMANCE TESTS OF SFD-315 MAGNETRON

Findings and interpretation by S-F-D Laboratories regarding the ASDE-2 modulator are summarized in Appendix II. Life expectancy of the three 4PR60 modulator switch tubes appeared to be improved by the modifications; one set of three 4PR60 tubes operated at NAFEC for approximately 1300 hours in the modified modulator of Channel B while the first 4200 hours of life were being accumulated by the SFD-315 magnetron, Serial G12E.

After the modulator had been modified by AIL and reinstalled in Channel B of the NAFEC ASDE-2, performance tests were repeated. The second set of data, listed in Table V, shows the performance of the SFD-315 magnetron after incorporation of the AIL modulator modifications in comparison with performance of a new type BL-M006 magnetron in Channel A.

The basic modification proposed by AIL involved replacement of the storage capacitor with a capacitor of lower internal inductance and introduction of a tapped inductor, in series with the new storage capacitor, to transfer and shape the modulator pulse, between the 4PR60 modulator tubes and the SFD-315 magnetron. Figure 6 shows how the tapped inductor was mounted within the modulator.

Although pulse duration could be reduced by adjustment of the tapped inductor, internal interference to the radar system could not be eliminated. The effect of this interference is illustrated in Figure 7, which shows how annular rings obscured the airport target in the vicinity of the center of the plan position display. Interference-free operation of Channel B was reestablished only after removal of the tapped inductor. Appendix IV contains a summary of findings during unsuccessful local efforts to make Channel B operate satisfactorily with the AIL modifications.

Figure 8 shows how the Channel B transmitter pulses appeared, in comparison with the pulse obtained from a new BL-M006 magnetron in Channel A, as the series inductance was changed by moving the adjustable slide connector between taps 1, 2, and 3 of the AIL modification.

As a satisfactory output pulse could not be obtained with either the SFD or AIL modifications, tests were conducted using S-F-D's laboratory-built modulator to drive the SFD-315 magnetron. The S-F-D modulator, which was developed for life testing SFD-315 magnetrons was then used to modulate the SFD-315 magnetron in Channel B. The output of the magnetron was delivered to the ASDE antenna in lieu of a dummy load. Measurements of the output pulse showed pulse widths of approximately 35 ns were being obtained.

TABLE V

OPERATING CONDITIONS ESTABLISHED IN ASDE-2 FOR COMPLETION OF MAGNETRON LIFE TEST WITH AIL MODULATOR MODIFICATIONS

BL-M006 Operation in Unmodified Channel A
SFD-315 Operation in Channel B Modified by AIL

Operating Parameter	BL-M006 Magnetron in Channel A	SFD-315 Magnetron in Channel B
Transmitter Frequency, Gc/s	24.0	24.1
Pulse Duration, ns	18.0	29.0
Rise Time, ns	4.0	20.0
Decay Time, ns	10.0	35.0
Pulse Repetition Rate, pulses/s	14,400	14,400
Average Power, W	12.5	16.5
Peak Power, kW	48.7	40.2
Magnetron Current, mA	4.0	4.0
Modulator High Voltage, kV	13.5	19.5
Modulator Current, mA	17.0	16.0
Voltage Standing Wave Ratio, VSWR	1.10:1	1.10:1
Duty Cycle	.00026	.00041

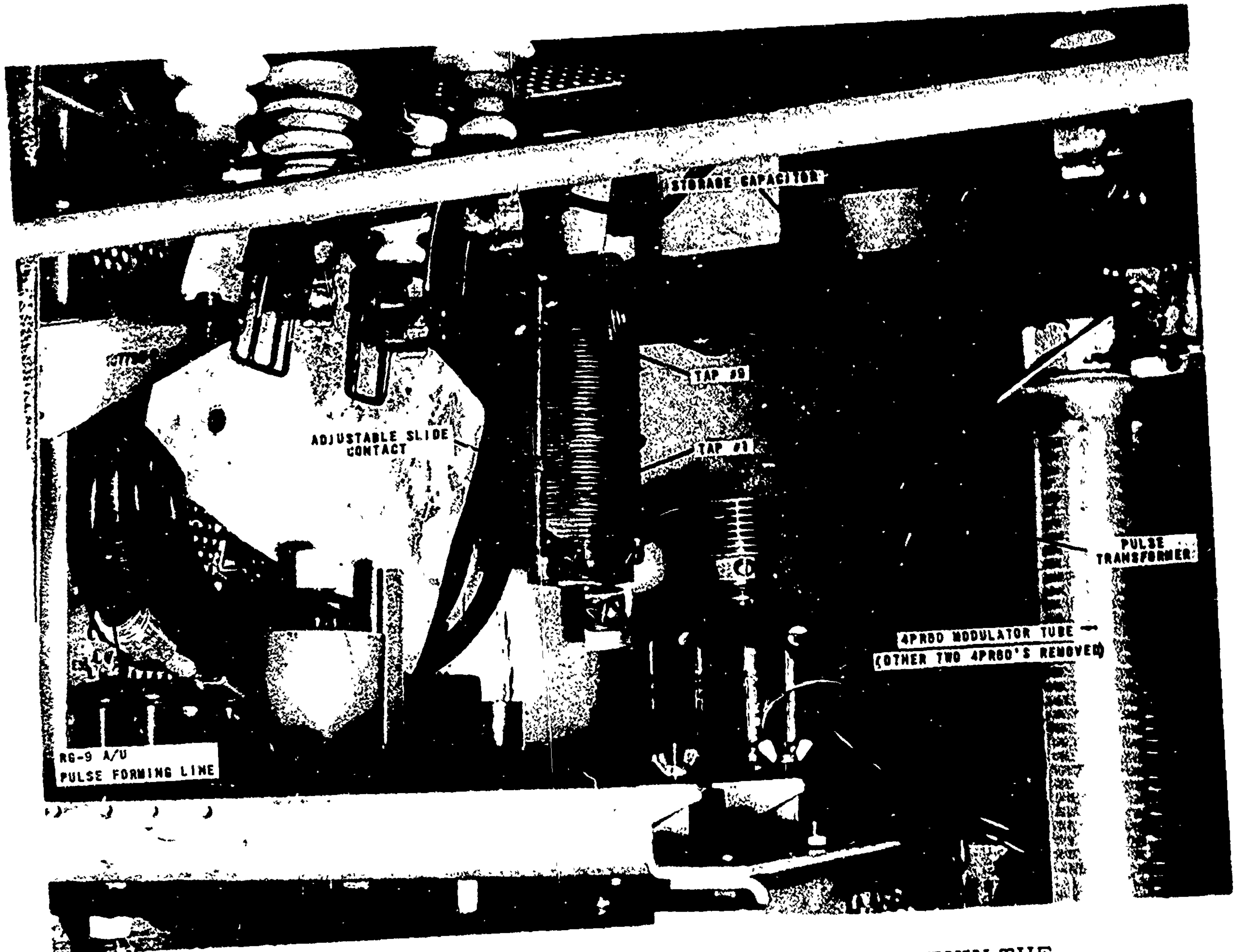


FIG. 6 TAPPED INDUCTOR INSTALLED BY AIL WITHIN THE CHANNEL B MODULATOR

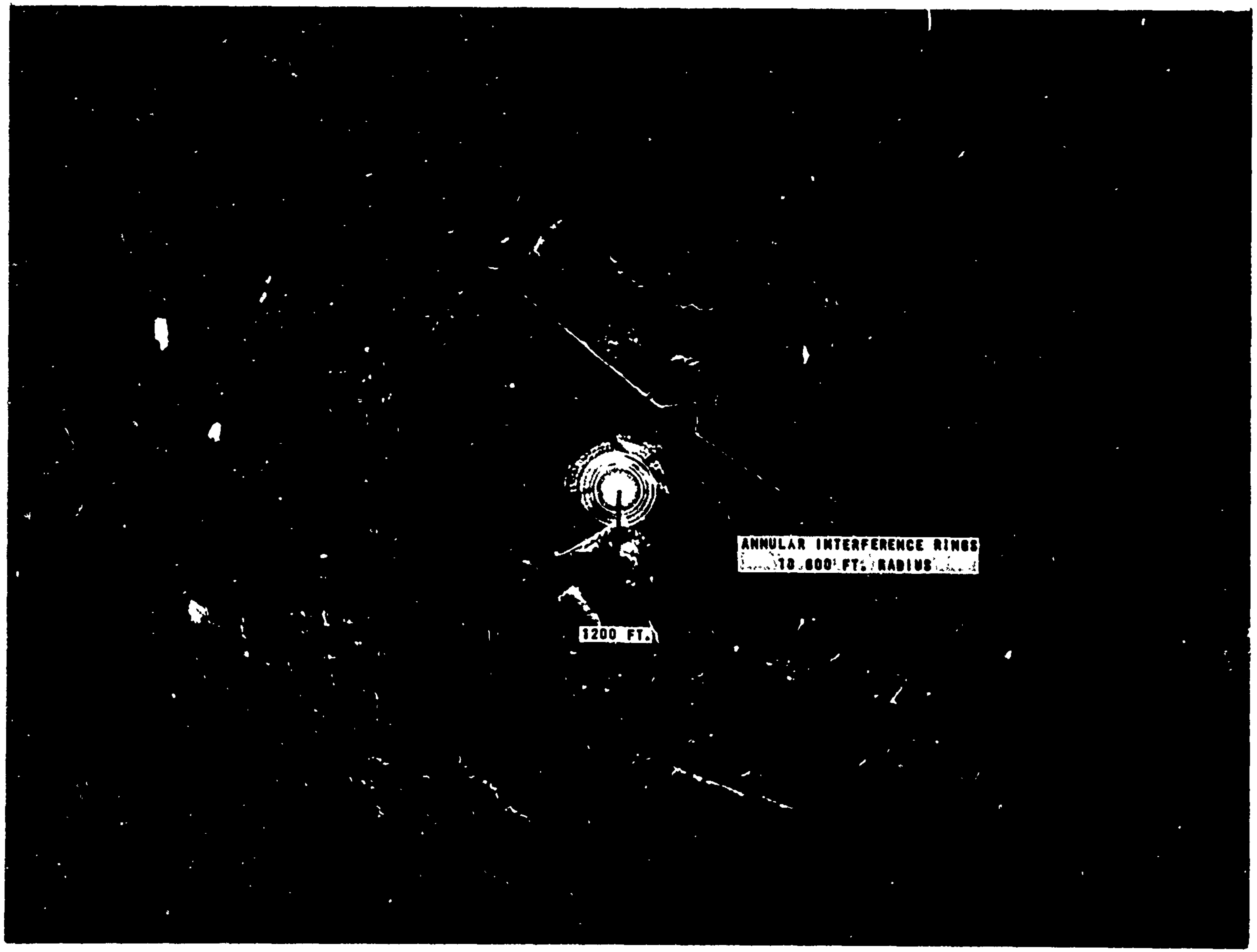
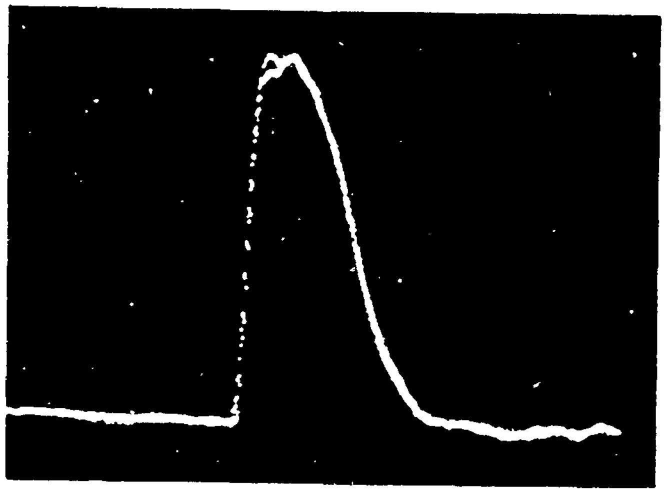
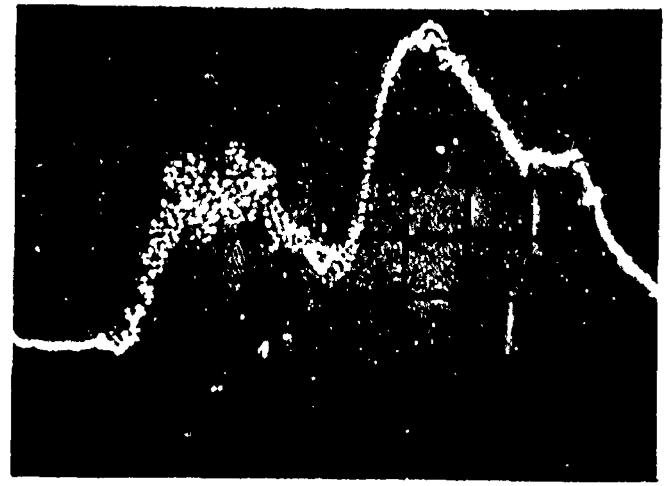


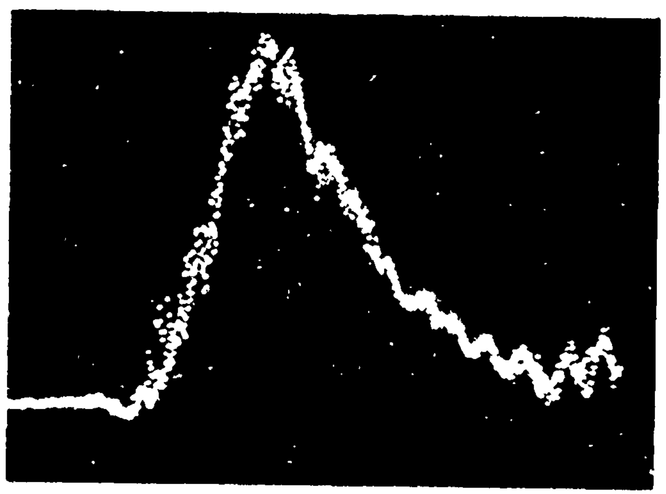
FIG. 7 INTERFERENCE DISPLAYED ON THE PPI DURING TEST OF AIL MODULATOR MODIFICATIONS



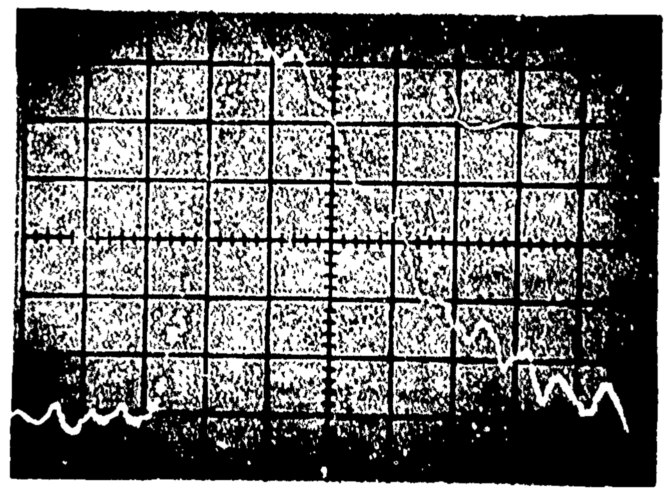
BL-M006 MAGNETRON PULSE, CHANNEL A
(WITH SOLID STATE DUPLEXER IN OPERATION)



SFD-315 MAGNETRON PULSE, CHANNEL B
WITH AIL INDUCTOR SET AT TAP #1



SFD-315 MAGNETRON PULSE, CHANNEL B
WITH AIL INDUCTOR SET AT TAP #2



SFD-315 MAGNETRON PULSE, CHANNEL B
WITH AIL INDUCTOR SET AT TAP #3

FIG. 8 TYPICAL WAFEFORMS REPRESENTING TRANSMITTER PULSE OF CHANNEL A IN COMPARISON WITH TRANSMITTER PULSES OBTAINABLE FROM CHANNEL B AFTER AIL MODIFICATION

Radar Resolution - The pulse duration measurement was confirmed by comparing the range resolution of Channel B with that of Channel A. Effects of pulse-shape deviations were investigated by observing the display of discrete targets on the A-scope presentation of the ASDE-2 during operation of both the unmodified Channel A and the modified Channel B. Four corner reflectors were placed in line along a selected azimuth, approximately 4000 feet from the radar. The first two, 18-inch reflectors, were positioned 20 feet apart. The separation between the second and third reflectors was 40 feet. The third and fourth, 9-inch reflectors, were also placed 20 feet apart. The drive motor for the radar antenna was turned off and the radiation beam manually aligned until the video signals on the A-scope could be correlated with the four corner reflectors.

During the early performance tests, before the Channel B modulator was modified by AIL, it was found that test corner reflectors had to be separated in range by approximately 35 to 40 feet before they could be resolved individually when the SFD-315 magnetron was operating in Channel B. Reflectors 3 and 4 became distinguishable, as shown in Figure 9, on the A-scope once they were separated by 35 feet while reflectors 1 and 2, separated by 20 feet, could not be resolved. The unmodified transmitter, delivering a pulse of 20 ns duration, produced distinguishable signals even though the reflectors were spaced no more than 20 feet apart. Figure 10 reveals representative presentation differences between the BOMAC BL-M006 and SFD-315 when the magnetrons operated at a power level of 12.5 watts.

The effect of small changes in pulse duration was not noticeable on the PPI of ASDE-2. Once the AIL modifications to the modulator of Channel B were removed, and a different storage capacitor, rated at 0.002 uF, substituted for the existing storage capacitor, pulses of some 29 ns duration were attained. The PPI presentation was useable but pulse power output was reduced. Resolution of the radar was examined on the A-scope of the ASDE-2. Radar targets would be distinguished on the airport surface some 4000 feet from the radar, when separated radially by at least one foot for each nanosecond of measured pulse duration.

Life Test-[7] The life of the magnetron was taken as the total number of hours during which satisfactory operation was attained in the ASDE-2 under high voltage modulation. Satisfactory operation of the

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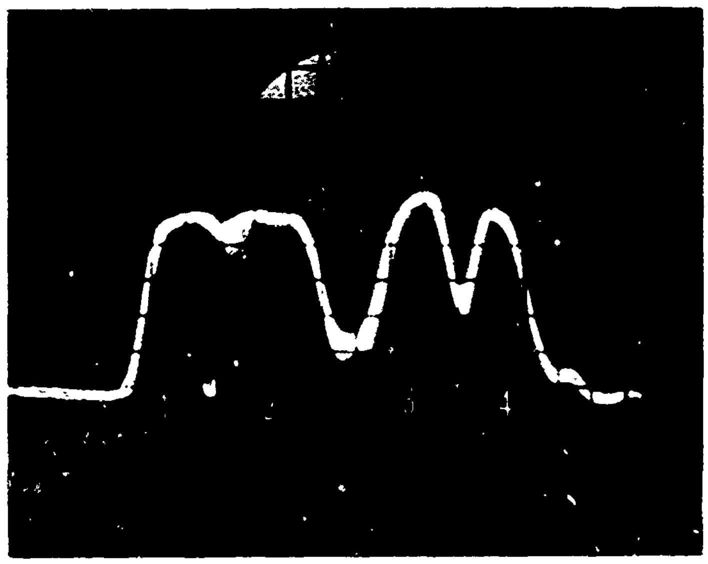
[7] Life test for four SFD-315 magnetrons at the contractor's plant was accomplished in three specially constructed laboratory modulators. A simulated RF load device was imposed on these magnetrons during life tests.

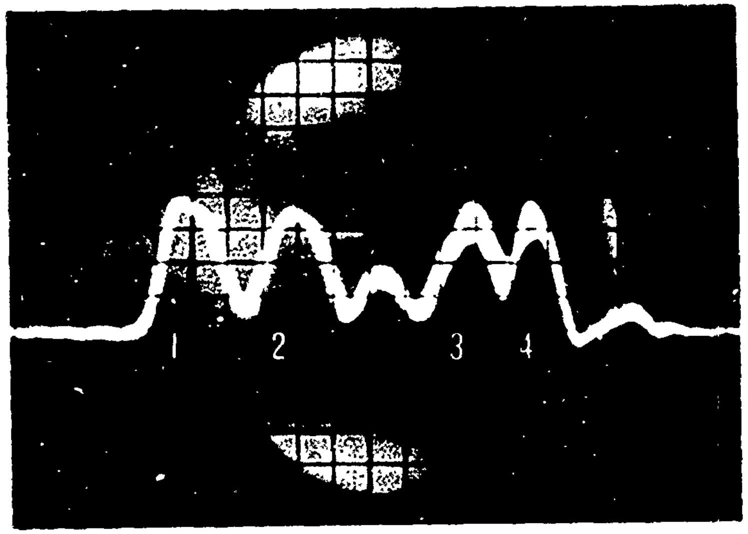


SFD-315 MAGNETRON IN CHANNEL B (MODIFIED BY S-F-D)

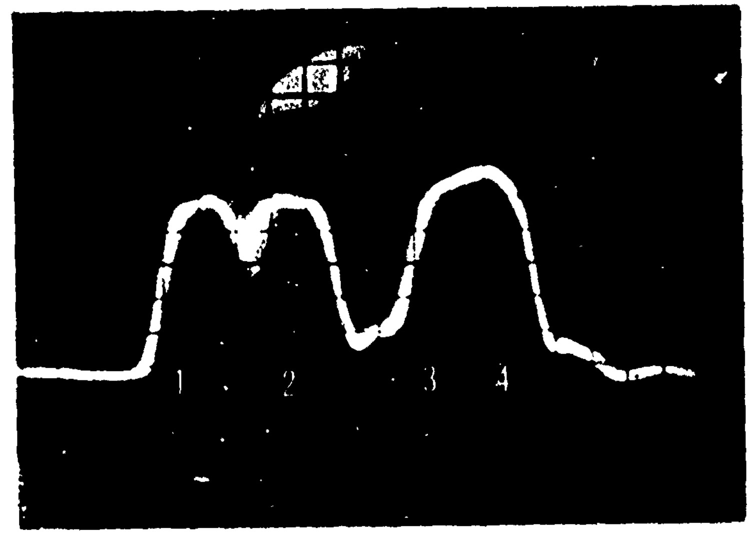
LEGEND

RADAR RETURNS 1 AND 2 FROM 18 INCH REFLECTORS
RADAR RETURNS 3 AND 4 FROM 9 INCH REFLECTORS

FIG. 9 VIDEO SIGNALS REPRESENTING RADAR ECHOES FROM CORNER REFLECTORS; AVERAGE TRANSMITTER POWER AT 15 WATTS



BL-M006 MAGNETRON IN CHANNEL A
(UNMODIFIED)



SFD-315 MAGNETRON IN CHANNEL B
(AS MODIFIED BY S-F-D)

LEGEND

RADAR RETURNS 1 AND 2 FROM 18 INCH REFLECTORS
RADAR RETURNS 3 AND 4 FROM 9 INCH REFLECTORS

FIG. 10 VIDEO SIGNALS REPRESENTING RADAR ECHOES FROM CORNER REFLECTORS; AVERAGE TRANSMITTER POWER AT 12.5 WATTS

magnetron was presumed when an acceptable presentation was obtained on the radar indicator. As long as the average power remained equal to or higher than specified for the transmitter and a stable transmitter pulse was obtained, life tests were continued with all other operating conditions as prescribed by the manufactorer of the magnetron. (See Table III.)

From time to time it was necessary to vary the level of the modulator high voltage in order to comply with the S-F-D recommendations to maintain average magnetron current at a constant indicated level of 4.0 milliamperes. Otherwise, the high voltage supply was maintained at 13.5 kilovolts. Operating time was indicated by the elapsed-time indicator in the ASDE-2.

During the first 4200 hours of cathode operation, the magnetron was operated with the modulator as modified by S-F-D. When the modulator was removed for further modifications by AIL, life testing was interrupted for a period of approximately six months. After the re-modified modulator was reinstalled, it was adjusted as recommended by AIL. Prescribed performance levels were reestablished and an additional 800 hours of cathode operation were accumulated. The life testing was interrupted on other occasions so that the effect of the AIL changes could be studied and the performance of the radar optimized.

The SFD-315 magnetron, which was operated for an accumulation of 5000 hours, successfully demonstrated the durability of its cathode. However, for most of this time Channel B, was unable to satisfy ASDE-2 requirements for pulse duration and peak power output.

The first 4200 hours of life testing in the Channel B were accomplished with the modulator as modified by S-F-D. No time was accumulated during several months while modifications were being devised for the modulator by AIL. The next 800 operating hours in the ASDE-2 were accomplished after the AIL modifications had been incorporated in the modulator. Then, the magnetron was modulated for several additional hours with different adjustments of the tapped inductor and a variety of capacitors. Efforts to clarify the PPI presentation and find a satisfactory adjustment for the AIL inductor were not successful but these efforts demonstrated ability of the magnetron to withstand the stress of various types of imperfect modulation.

Although this magnetron operated consistently through most of its life tests, when the configuration of the modulator components was changed, the magnetron pulse shape and other radar operating

conditions also changed. Restoration of any internal modulator configuration resulted in restoration of the corresponding magnetron performance as observed earlier with the same modulator configuration.

After 5200 hours there was no apparent deterioration of the magnetron performance. It continued to operate reliably and to respond consistently when various types of modulator pulses were reapplied.

Installation of Magnetron at NAFEC - Although the steel door could be closed after it was reinstalled on the transmitter-receiver cabinet, the physical clearance between the magnet of the magnetron and the cabinet door did not meet the minimum recommendations of the warning notice on the magnetron, which requires a minimum of four inches separation from external magnetic materials. Throughout the tests at NAFEC, the steel cabinet doors were removed from the transmitter-receiver cabinets of both channels.

Minor adjustments to mounting holes for the magnetron support bracket were made as required in order to obtain correct alignment of the magnetron connections with the ASDE-2 waveguide assembly.

Proximity of the steel door to the magnetron caused an action similar to a magnetic door catch. Furthermore, when the cabinet door was closed during transmitter operation, reduction in magnetron current of 0.5 ma was indicated on the control-panel instruments. No specific tests were made to determine the extent of magnetic interaction upon radar system performance. Throughout the performance and life tests, the equipment within the transmitter-receiver cabinet of both channels was operated with the steel door removed.[9]

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[9]Although the evaluation was not designed to determine life of BL-M006 magnetrons, it was considered noteworthy that one of these magnetrons performed for more than 2000 hours in Channel A. Local personnel attributed this unusual length of service to two factors: a. nearly continuous operation (during life test of the Solid State Duplexer) resulted in a minimum number of shut-down and warm-up cycles; and b. removal of the steel cabinet door eliminated frequent magnetic interactions of the steel with the permanent magnet of the BL-M006 magnetron.

Tests of Solid State Duplexer: The Solid State Duplexer was tested for effects upon system noise figure, insertion loss, system sensitivity, close-in coverage (minimum range to typical airport surface targets) and operating life. In order to accomodate the new duplexer, it was necessary to lower the keep-alive current in the TR tube to approximately 1/3 the current required by the original TR tube.

Noise figure and output power of the radar were measured in accordance with standard procedures defined in the applicable ASDE-2 instruction books and maintenance handbook. From measurements of power transmitted through both of the old and new duplexers, insertion loss differences were derived. As originally constructed, the new Solid State Duplexer attenuated received signals by approximately 20 dB due to an error in the waveguide transition. (See Figure 11.) Once this error was corrected by the manufacturer, the performance of the new duplexer was generally superior to performance of the original equipment of ASDE-2 (See Figure 12.)

A minor electrical change, to reduce TR keep-alive current from the level of 400 uA of the original equipment to 125 uA for the new duplexer, involved the simple addition of a 3.3 megohm resistor in series with the connection to the TR tube. No difficulties were encountered in aligning the radar after installation of the new duplexer in Channel A of the NAFEC ASDE-2.

Results of the performance tests, presented below, are summarized in Table VI.

Effect Upon Noise Figure - Noise figure with the original duplexer was measured to be 16.5 dB. Noise figure with the Solid State Duplexer was measured by the same procedure to be 17.2 dB at the start of the life test. Both these noise figures were less than the allowable upper limit of 19.0 dB cited in the applicable maintenance handbook.

After the Solid State Duplexer had been in operation for approximately 1800 hours, the noise figure was again measured and found to be 18.3 dB, a value which was still within allowable limits. During that 1800 hours there was no need to replace receiver crystals. The increase of noise figure from 17.2 dB to 18.3 dB could have been due entirely to gradual deterioration of the receiver crystals and need not have been due to changes in the Solid State Duplexer. Other experience had indicated that receiver crystals become noisy and had to be replaced in the ASDE-2, as originally equipped with the conventional duplexer, after operation for less than 600 hours.

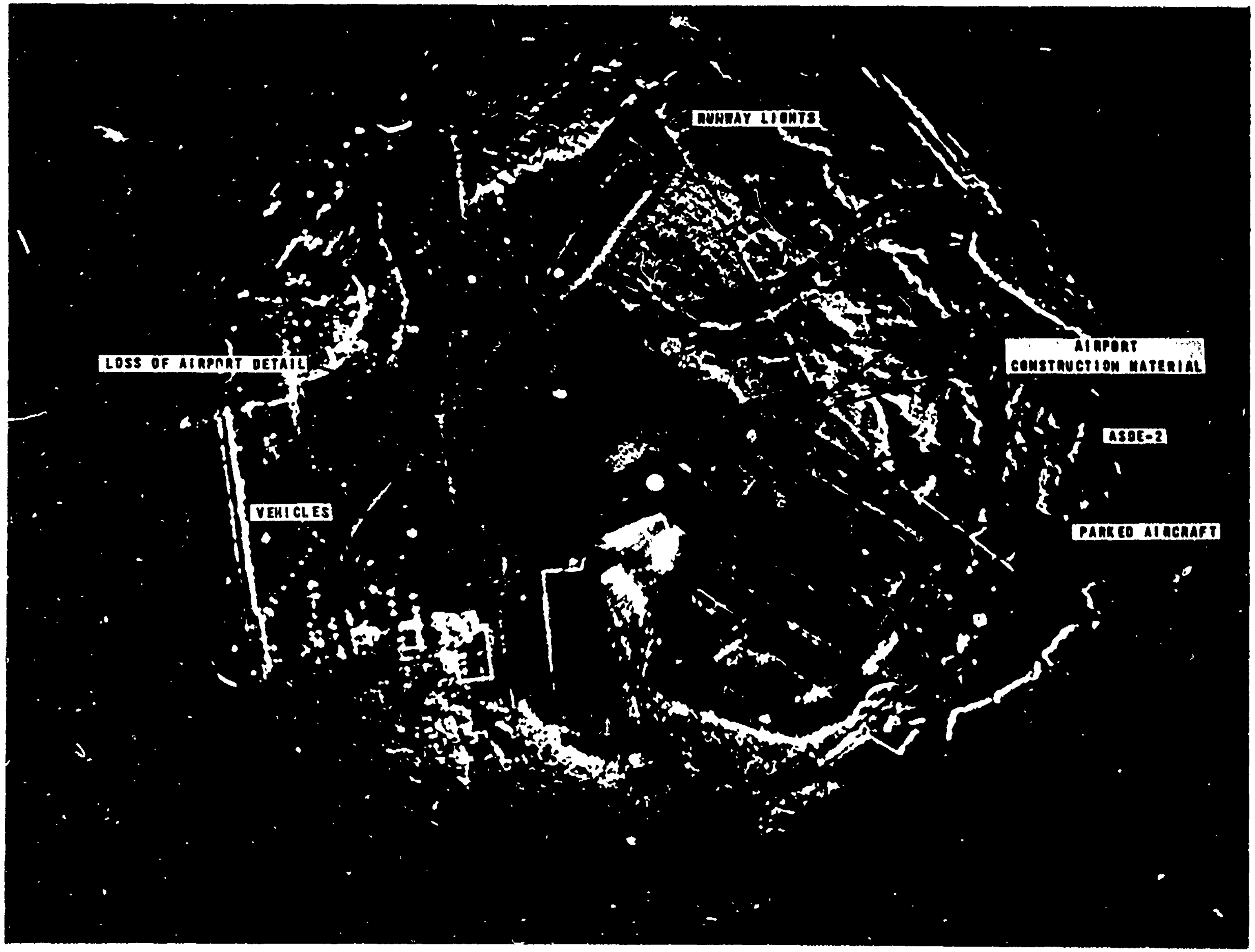

FIG. 11 PPI DISPLAY OF VIDEO SIGNALS PRIOR TO CORRECTION OF ERROR IN SOLID STATE DUPLEXER ASSEMBLY

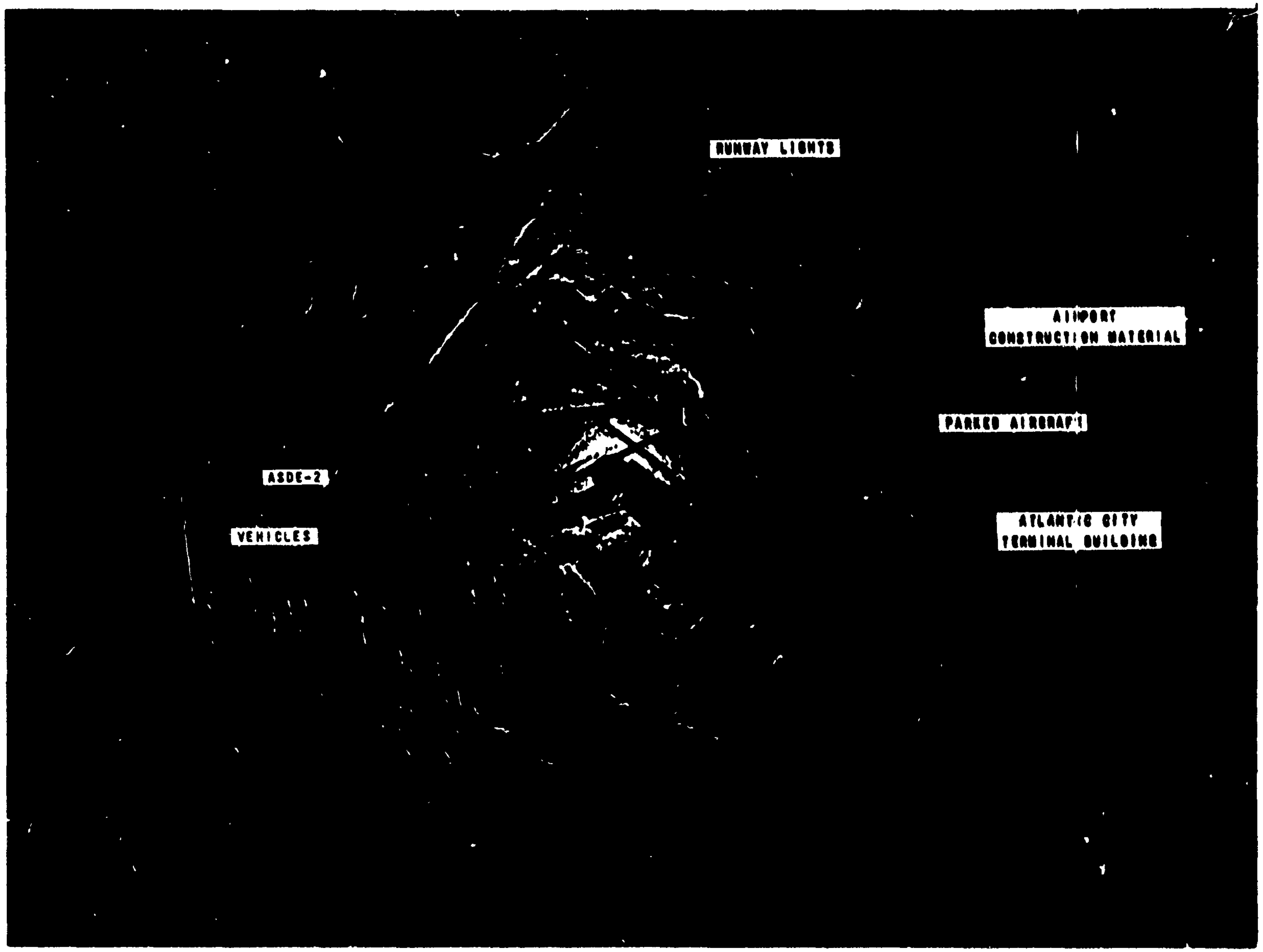

FIG. 12 PPI DISPLAY OF VIDEO SIGNALS AFTER CORRECTION OF ERROR IN THE SOLID STATE DUPLEXER BY ITS MANUFACTURER

TABLE VI

COMPARISON OF OPERATING CONDITIONS FOR SOLID STATE DUPLEXER AND CONVENTIONAL DUPLEXER IN ASDE-2 AT NAFEC

Operating Parameter	Conventional Duplexer	Solid State Duplexor	ASDE-2 Requirements
Sensitivity, dBm	-82.0	-87.0	-80.0
Minimum Range, Ft.	175.0	125.0	---
Average Power Output, W	9.5	10.2	11.7 Maximum
Noise Figure, dB	16.5	17.5	19.0 Maximum
Magnetron Current, mA	4.0	4.0	5.0 Maximum
Modulator High Voltage, kV	18.0	18.0	18 - 20
Modulator Current, mA	16.0	16.0	28.0 Maximum
Frequency, Gc/s	24.16	24.16	23.80 to 24.27
Repetition Frequency, PPS	14.4	14.4	15,000 nominal
Pulse Duration, ns	21.0	21.0	20 or less
TR Tube Keep-Alive Levels, uA	400.0	120.0	200 - 400

At the time formal life tests were terminated, the receiver crystals installed at the start of the life test had not yet deteriorated sufficiently to warrant their replacement although they had been employed for 2000 hours of operation under protection of the Solid State Duplexer.

Effect of Duplexer on Transmitted Pulse - The transmitted pulse, delivered by BL-M006 magnetron, (Serial No. 6112-401), was detected and photographed after it had passed through the Solid State Duplexer installed in Channel A. The photograph in the upper left corner of Figure 8 typifies the character of the detected pulse as observed frequently throughout the engineering and life tests.

Average output power of the radar was measured to be 9.5 watts while the conventional duplexer was part of the transmission system and 10.2 watts after the Solid State Duplexer had been installed. All conditions of the radar were kept the same during both measurements. Insertion loss due to the Solid State Duplexer was, therefore, in the order of 0.2 dB less than insertion loss due to the conventional ASDE-2 duplexer. Absolute values of insertion loss were not measured.

The BL-M006 magnetron continued to operate without deterioration of its pulse shape for the full 2000 hours of the formal duplexer life test. At the time life tests were terminated, the transmitter pulse shape was not noticeably different than at the start of testing; some reduction of peak power was noted but replacement of the magnetron was not required. (During preparation of this report, the accumulated operating life of the magnetron exceeded 2500 hours.)

Effect of Duplexer on Receiving System Sensitivity - Sensitivity measurements conformed to procedures described in a Handbook on Radio Frequency Interference.[8] The transmitter was held inoperative along with special receiver control circuits, such as Sensitivity Time Control (STC) and Fast Time Constant (FTC), while a calibrated test signal was introduced to the receiver through the directional coupler in the waveguide system.

The amplitude of the calibrated test signal was adjusted so that the peak of the amplified signal, observed as video on an oscilloscope after passing through the receiver, was just visible at the top of the

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[8] Handbook on Radio Frequency Interference, Vol. 2, Frederick Research Corporation, Wheaton, Maryland.

receiver noise. Change of sensitivity, resulting when the new duplexer was substituted for the conventional model, was derived from the calibrated dial of the signal generator which was graduated in dBm. Sensitivity observations were repeated after brief periods of radar operation; in each case the radar was operated for several hours before the observation was taken.

During the initial engineering tests, the sensitivity of the complete receiving system in Channel A was measured to be -82.0 dBm; during these measurements, the conventional duplexer was in operation. When the Solid State Duplexer was installed and operated in Channel A, under the same conditions, the overall receiving system sensitivity was found to be -87.0 dBm. Throughout the subsequent 2000 hours while the Solid State Duplexer was being life tested, there was no evidence that the system sensitivity had deteriorated from its initial value.

Close-in Coverage - The appearance of the display on the Plan Position Indicator (PPI) was observed in the vicinity of the radar for effects upon close-in coverage in terms of minimum range to typical airport surface targets. Various targets were maneuvered within a radius of 200 feet and their position on the ground marked when the radar return was no longer discernable on the display. The distance from the base of the tower to this mark was measured with a steel tape. Pedestrians and jeeps were maneuvered on nearby grassy section of the airport and on concrete ramps. Jeeps, taxiing aircraft and other vehicles were observed on concrete taxi strips and parking ramps in the vicinity of the radar. Measurements of minimum range to actual targets were correlated with measurements made using a pulse signal generator to simulate airport targets at various distances.

In addition to the above tests, the radar output pulse shape was examined from time to time for evidence of magnetron deterioration.

The radius of the area surrounding the ASDE-2, within which typical ground targets could not normally be detected when the conventional duplexer was installed in Channel A, was approximately 175 feet. Once the solid state duplexer had been installed in Channel A, surface vehicles and aircraft could be detected as targets on the PPI display as long as they did not penetrate a central area 125 feet in radius about the radar tower. Persons walking on the concrete aprons and taxiways could be detected as weaker radar targets often, but not always, as close as 170 feet from the radar tower. Persons could not normally be detected while standing or walking on grassy areas, but jeeps and larger vehicles

or aircraft could usually be detected while maneuvering on grassy areas outside the 125 foot radius about the radar tower.

In one test of close-in coverage, four airport vehicles were stationed near the North Ramp leading to the apron at the Atlantic City Airport Terminal. Each vehicle was positioned facing the tower. The ground distance to the first vehicle, a station wagon, was 125 feet. The other vehicles, a jeep, a small oil truck and a sedan were each located 50 feet further away along the same radius. Figure 13 is an enlargement which shows the radar returns from these vehicles on the PPI display.

An artificial signal, comparable in magnitude to the radar return from a typical vehicular target, was injected into the waveguide system between the RF switch near the antenna and the Solid State Duplexer. The transmitter was disabled so the receiving system could be observed in operation without firing the TR tube. The test signal generator was synchronized with the trigger pulses which internally controlled the operation of the radar. A variable time delay in the test set allowed the artificial signal to simulate the approach of a target to the minimum range. As the test signal approached the range where actual targets had been observed to disappear from the PPI and A-scope presentations, the signal similarly disappeared. This effect was taken to indicate that recovery time of the TR tube in the Solid State Duplexer did not increase the overall recovery time of the receiving system of Channel A, which had been aligned for the best close-in coverage available by means of the existing maintenance adjustments.

<u>Life Test</u> - Life test of the Solid State Duplexer was based upon continuous operation of Channel A except for periods during maintenance, interruptions for engineering tests or unexpected interruptions because of power failure. Its operating life was based upon the number of hours it performed in the radar set under normal operating conditions.

Operation of the radar was regularly examined for deviation from starting reference levels. The quality of the PPI display was observed along with levels of the panel instruments, receiver noise, sensitivity, and output-pulse characteristics. (Schedule of observation presented in Table II.)

Records of maintenance were kept to show any requirement for replacement of receiver crystals and to expose any tendencies toward deterioration of system performance with the accumulation of operating time.

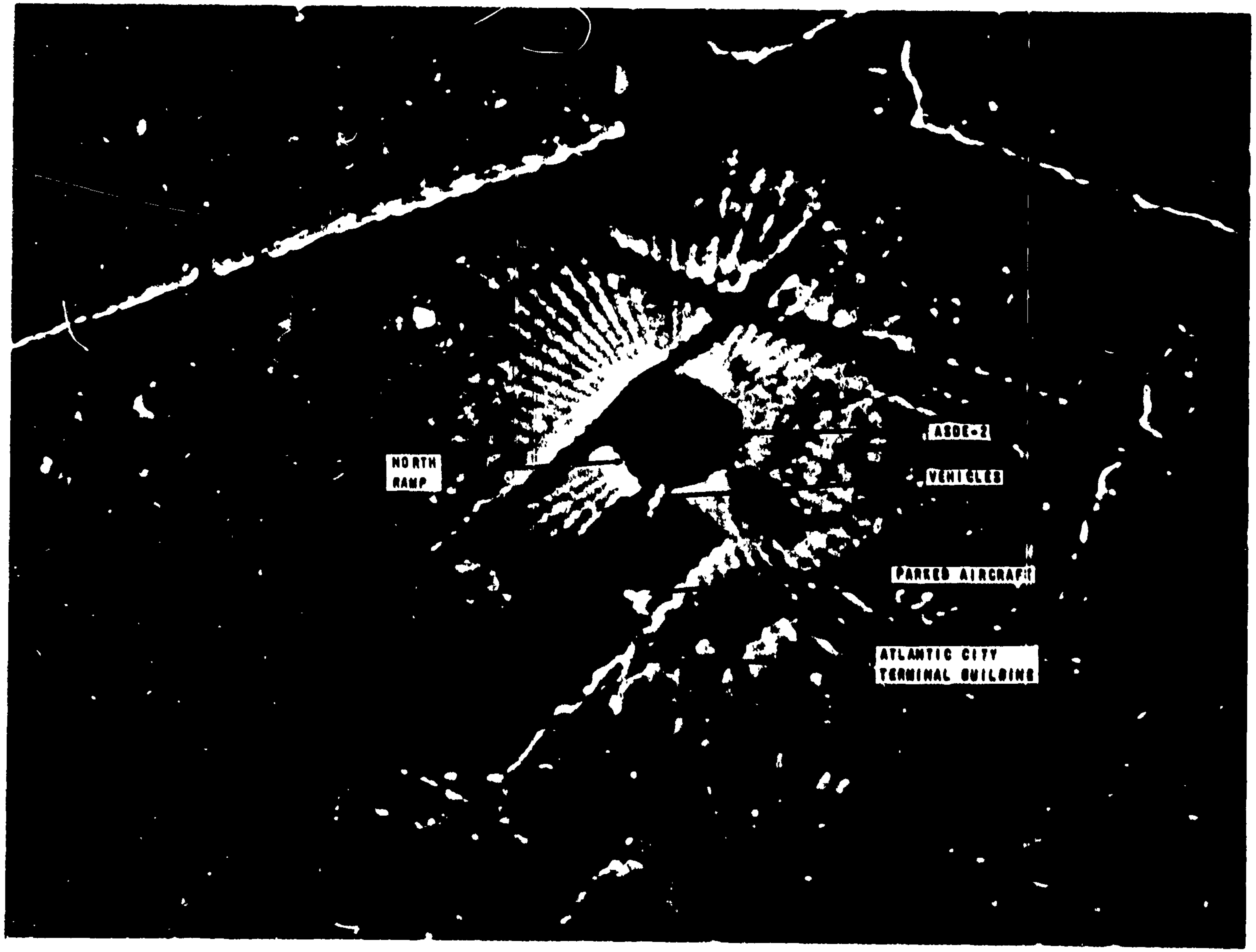

FIG. 13 PPI DISPLAY SHOWING RADAR RETURNS FROM FOUR VEHICLES POSITIONED NEAR THE RADAR TOWER

Throughout the test, the steel door was removed from the Channel A cabinet containing the duplexer and BL-M006 magnetron.

During the formal life test at NAFEC, the Solid State Duplexer performed for 2000 hours at the end of which time it was still operating normally; the maintenance PPI and the radar Panel Instrument Levels showed no evidence of duplexer deterioration. Small changes in the level of TR tube keep-alive current were observed after 1000 hours of operation; keep-alive current readings dropped temporarily from 125 uA to 90 uA but returned to normal after 1200 hours of operation had been accumulated. The temporary change in keep-alive current was attributed to power line voltage variations incidental to extensive construction work in the area adjacent to the ASDE-2.[10] Actual deterioration of the TR tube would have been indicated by a permanent current change and the starting levels could never have been reestablished. However, keep-alive current was attributed to power line voltage variations incidental to extensive construction work in the area adjacent to the ASDE-2.[10] Actual deterioration of the TR tube would have been indicated by a permanent current change and the starting levels could never have been reestablished. However, keep-alive current levels were found to vary from time to time between 95 and 125 uA.

During the preparation of this report, operation of the Solid State Duplexer was continued. The receiver crystals, installed especially for the life tests, were still in acceptable working condition and the system noise figure was measured at 18.5 dB after more than 2500 hours; in operational ASDE-2 radars, three to five sets of crystals had been found insufficient to cover such a long period of operation.

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[10] There were several days during which no power at all was available throughout extensive airport areas adjacent to the ASDE-2 Facility.

SUMMARY OF RESULTS

The results obtained from tests at NAFEC of the SFD-315 magnetron with the modified ASDE-2 modulator, and of the Solid State Duplexer, are summarized as follows:

1. The first SFD-315 magnetron failed after 144 hours; the second magnetron operated more than 5000 hours without degradation.

2. The best attainable values of transmitter pulse duration were 40 ns with the S-F-D modification, 35 ns with the S-F-D Laboratory test modulator, and 29 ns with the AIL modification. Specifications required pulse duration to be 20 $\pm$ 2 ns.

3. Peak power output delivered by the SFD-315 magnetron, with both the S-F-D and AIL modifications, was approximately 20% lower than that obtained from the BL-M006 magnetron when distortion to pulse shape was considered.

4. The AIL modification caused excessive interference on the PPI; the S-F-D modification caused no interference and produced a useable display.

5. The unmodified ASDE-2 Channel A could resolve corner reflectors at a longitudinal spacing of 20 feet at a distance of 4000 feet; Channel B, as modified by S-F-D and with the SFD-315 magnetron installed, could not resolve the same reflectos until they were separated longitudinally by at least 38 feet.

6. The Solid State Duplexer operated for over 2500 hours without noticeable deterioration or degradation in radar performance.

7. The best receiver noise figure measured with the Solid State Duplexer was 17.2 dB; the noise figure with the conventional duplexer was 16.5 dB. The maximum permissable limit was 19.0 dB.

8. One set of receiver crystals performed satisfactorily for more than 2500 hours in the radar receiver. These crystals were still in service upon termination of formal tests and while this report was in preparation.

9. The insertion losses in the transmit mode, due to the Solid State Duplexer, was 0.2 dB less than that measured for the conventional duplexer.

10. Sensitivity of the radar receiver measured -87 dBm with the Solid State Duplexer installed; it was -82 dBm with the conventional duplexer; required operating sensitivity of the ASDE-2 was -80 dBm.

11. With the Solid State Duplexer installed in Channel A, surface vehicles and aircraft were detected as targets on the PPI display at and beyond a radius of 125 feet from the radar tower. When the conventional duplexer was operated under the same conditions, observation of ground targets could not be observed closer than 175 feet from the radar tower.

12. During formal tests of the Solid State Duplexer, the BL-M006 magnetron operated reliably without deterioration of its pulse shape for more than 2500 hours. This magnetron was left in operation and was still in acceptable working condition at the time this report was prepared.

CONCLUSIONS

Based on the results of the evaluation of new K-band components, including the SFD-315 ICEM magnetron and a Solid State Duplexer, conducted under Project 241-C04-01V, it is concluded that:

1. Satisfactory performance can not be achieved using the modifier modulators provided for operation of the SFD-315 magnetron in ASDE-2.

2. The SFD-315 magnetron is suitable for ASDE applications with a compatible modulator, and may be expected to operate satisfactorily for more than 5000 hours.

3. The Solid State Duplexer is a suitable replacement for the original duplexer in ASDE-2.

RECOMMENDATIONS

Based on the evaluation of new K-band components, including the SFD-315 ICEM magnetron and a Solid State Duplexer for Airport Surface Detection Equipment ASDE-2, it is recommended that:

1. The SFD-315 magnetron not be adopted by FAA as a replacement for the BL-M006 magnetron in existing operational ASDE-2 equipment.

2. The Solid State Duplexer be adopted by FAA as a replacement duplexer for existing operational ASDE-2 equipments.

3. Procurement specifications for future models of ASDE K-band radar include provisions for the following:

   a. Incorporation of a Solid State Duplexer

   b. Application of an ICEM type of magnetron such as the SFD-315, with a compatible modulator.

   c. Mounting of the magnetron where the field of its permanent magnet is not exposed appreciably to magnetic materials.

APPENDIX I

SUMMARY OF REQUIREMENTS IN MAGNETRON DEVELOPMENT SPECIFICATIONS

Radar Parameter	Specification Requirements	Specification Life Test-End Point	Remarks
Operating frequency	Fixed, between 23,800 and 24,270 Mc	Not less than 23,800 Mc/s	Operation in lower half of band
Peak power output	At least 40 kw at start of tests Not more than 55 kw	Power output at the end of the tube life 80 percent of the power at the start of life test	Peak power to be computed from average output power and duty cycle
Duty cycle	0.0003 with pulse duration of 0.02 usec.	A duty cycle in excess of .0003 as determined by pulse duration	To be measured with duty cycle starting peak pulse power output of 40 kw minimum
RF pulse duration	0.02 $\pm$ 0.002 usec.	0.018 usec, minimum 0.022 usec, maximum	RF pulse to be measured at 1/2 power points of main lobe only
Pulse repetition rate	15 kc/s, nominal	15 kc/s adjusted to obtain required duty cycle	For duty cycle as indicated in specification requirements above

SUMMARY OF REQUIREMENTS IN MAGNETRON DEVELOPMENT SPECIFICATIONS (Continued)

Radar Parameter	Specification Requirements	Specification Life Test-End Point	Remarks
Efficiency	Not less than 15 percent	Less than 15 percent	To be computed from estimated peak voltage and average input and output power
Load stability	1.0 percent into a VSWR of 1.5:1	Greater than 2.0 percent	To be measured as specified in Signal Corps Technical Requirements, SLC-7001/57B
Rise and Decay Time	Not to exceed .005 usec.	Greater than .005 usec	Rise and Decay dependent upon the pulse characteristics
Life	Not less than 250 hours	Less than 250 hours	Expected service live is 5000 hours
Overall contributions for operation during Life Tests	Operated with a pulse duration of 0.02 usec. at a duty cycle of .003 and peak power output of 40 kw min.	1. Pulse duration greater than .022 usec. 2. Duty cycle in excess of .0003 3. Starting peak power of less than 40 kw	Pulse characteristics to be measured as specified in Signal Corps Technical Requirements SCL-7001/57B
Peak Pulse Modulator Voltage	Not to exceed 35 kv	35 kv	Normally operated at approximately 15 kv

APPENDIX II

INTERPRETATION BY S-F-D LABORATORIES, INC., REGARDING MAGNETRON PERFORMANCE IN ASDE-2 AT NAFEC

Review of ASDE-2 Modulator Design

Excessive duration of the transmitter-pulse from the SFD-315 magnetron was interpreted by S-F-D Laboratories, Inc., as an effect of a basic and inherent deficiency of the modulator system of the ASDE-2. This deficiency was explained by SFD as inability of the modulator-driver circuits to provide sufficient grid drive to the 4PR60 tubes. This condition was considered to result in a mismatch between the modulator and magnetron and caused an increase in the duration of the transmitter pulse.

The principal problem, therefore, appeared to be associated with the design of the driver circuit preceding the modulator. The manufacturer of the 4PR60 tubes had recommended Class C operation, with a peak anode voltage not to exceed 18 kv, a peak positive voltage of 1200 volts at the screen, and a negative bias voltage of 800 volts at grid #1. The drive pulse to grid #1, under load conditions was required to be at least 200 volts positive in order to obtain optimum service during pulsed operation.

The contractor's analysis indicated that the original modulator-circuit design did not meet any of the above requirements; the 4PR60 tubes were found to be operating as Class A amplifiers. Furthermore, the 3C45 thyratron was incapable of driving the 4PR60 grids to a proper positive level. The lack of grid drive resulted in 4PR60 tube life in the order of a few hundred hours instead of 1000 to 1500 hours life expectancy cited by its manufacturer. At the request of S-F-D Laboratories, Inc., a manufacturer of 4PR60 hard tubes, United Electronics Co. studied the ASDE-2 modulator and reported that the tubes are suffering from "sleeping sickness," i.e , cathode-structure surface contamination resulted in an inadequate level of electron emission.

Rejuvenation of 4PR60 tubes, which apparently had failed in the ASDE-2 was reported to have been accomplished by the hard-tube manufacturer. The rejuvenated tubes were then installed and operated successfully in other circuits where operating conditions were established according to the manufacturer's recommendations. After a short period of marginal performance, the tubes were found to perform at satisfactory operating levels and exhibited operating lives which closely approximated the manufacturer's claims.

Contractor's Measurements of Pulse-Duration

The NAFEC transmitter pulse-duration did not correspond with the contractor's laboratory measurements made on a similar SFD-315 magnetron installed in a mock-up model of the ASDE-2 modulator. Therefore, another series of tests was conducted by the contractor in order to explore whether there were other discrepancies which could explain the differences between the results in the laboratory test setup and in the NAFEC operational environment.

As a first step, the contractor removed all modifications it had made to the Channel B modulator at NAFEC, with the exception of the magnetron filament transformer. A BOMAC BL-M006 magnetron was substituted for the SFD-315 type. The electrical characteristics of the restored Channel B modulator were then compared with those of the unmodified modulator. The transmitter pulse-duration exceeded that transmitted by Channel A. Visual inspection of the Channel B modulator-circuitry by S-F-D personnel revealed that the modulator coupling capacitor C-10 shown in the schematic diagram[1] for the modulator had a value of 0.002 uF. The coupling capacitor, C-10, should have had a value of 0.001 uF. The corresponding component in the Channel A modulator was found to be a 0.001 uF capacitor. Capacitor C-10 in Channel B was then replaced with a 0.001 uF unit. This correction allowed Channel B to produce a normal transmitter pulse. The SFD-315 magnetron was reinstalled. At first, the duration of its output-pulse also appeared to be normal while the modulator voltage was below 10 kv.

During the ensuing operation of the ASDE-2, it was noted that as the modulator voltage increased above 10 kv, the SFD-315 magnetron entered a double-pulse mode of operation. A check of Channel A while operating at 14.0 kv and 4.0 milliamperes respectively did not reveal any evidence of double-pulsing by the BL-M006 magnetron. The cause of double pulsing was not identified positively. The 0.002 uF capacitor was reinstalled and a single-pulse mode of operation was thereby re-established.

Modulator Grid-Voltage Effect: As its next step, the contractor measured modulator grid-drive voltage. Only 560 volts were found to be available to drive the Channel B modulator as compared to 670 volts for Channel A. Investigation of the modulator circuitry of Channel B of the radar revealed that a section of Type RD 8/U coaxial cable, which

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[1] Instruction Book, Airport Surface Detection Equipment, Model ASDE-2, Volume 3, Section 12, Figure 12-8.

forms the delay line in the plate circuit of the 3C45 thyratron in the Channel B modulator, was considerably shorter than the corresponding length of cable found in Channel A. When this shortened cable was replaced with one of proper length, the peak grid-drive voltage was increased from 560 to 660 volts.

Modulator Grid-Drive Improvements: During the long-life K-band transmitter tube-development program, the contractor, aware of the low grid-drive levels existing in the ASDE-2 modulator system modified the 3C45 thyratron cathode circuit at NAFEC and thereby increased the modulator-grid drive-pulse voltage from approximately 700 positive to 900 volts positive. This grid-drive level approached the requirements of the magnetron but was not considered by S-F-D Laboratories to be the ideal magnetron drive condition. Attempts to further increase the grid-drive levels were unsatisfactory and were abandoned.

APPENDIX III

SUMMARY OF CHANGES TO ASDE-2 MODULATOR PROPOSED BY AIL FOR OPERATION WITH SFD-315 MAGNETRON

The changes made in a modulator of ASDE-2 by the magnetron-development contractor were assumed to be correct with respect to mounting provisions, and other minor mechanical adjustments to the internal configuration. These changes were described in the contractor's field conversion manual.[1] Additional changes were proposed by Airborne Instruments Laboratory, (AIL) in February 1965 after a laboratory method had been developed for reducing the duration of the transmitted pulse delivered by the SFD-315 magnetron. The changes recommended in an AIL final report[2] are summarized as follows:

1. New Filament Transformer - The SFD-315 magnetron was rated at a filament current of 5 amperes at 15 volts. The new filament transformer, Type LCF-1 manufactured by Pulse-Tronics, Inc.[3] had been chosen and installed in the ASDE-2 modulator by S-F-D Laboratories; it was not removed during the magnetron test program. It had lower capacitance and was somewhat larger in physical size than the original ASDE transformer, but it fit satisfactorily into the modulator compartment.

2. Change of Energy Storage Capacitor - The energy storage capacitor, (C10, FA 6617) was changed from the Chicago Condenser Type PAS 102-30-MS (.001 uF, 30 kV) to a Condenser Products Type ASG 202-40M (.002 uF, 40 kV.)

3. Addition of Tapped Inductor - A specially constructed inductor was connected between the energy storage capacitor in the modulator circuit and the SFD-315 magnetron. The inductor consisted of forty turns of #16 bare wire wound on a 1-3/4" x 5-1/2" Rexolite form and tapped in ten impedence increments. The nine taps of the inductor were provided to "compensate for variations in shunt capacity of the three 4PR60 tubes, wiring, magnetron, and the series inductance of the output coupling capacitor."

[1]Field Conversion Manual, Airport Surface Detection Equipment, Model ASDE-2, Type FA-6600, "Procedure Manual for Conversion of the ASDE-2 for use with the SFD-315 ICEM Coaxial Magnetron, S-F-D Laboratories Inc., Union, New Jersey (no date)

[2]Final Report of Investigation of ASDE-II Modulator Operation with the SFD-315 Magnetron, Airborne Instruments Laboratory, Deer Park, Long Island, New York, February 1965.

[3]Pulse-Tronics Inc., P.O. Box 42, Jerome Avenue Station, Bronx, N.Y.

The tap spacing versus inductance given in Table III-1, was based upon measurements of one inductor made during laboratory tests by AIL.

TABLE III-1

INDUCTANCE ASSOCIATED WITH TAPS OF SPECIAL INDUCTOR

Tap No.	No. of Turns	Inductance (Microhenries)
1	4	1.3*
2	8	4.3
3	12	8.3
4	16	10.0**
5	20	13.4**
6	24	17.2**
7	28	21
8	32	25

* Recommended inductance for operation of BL-M006 magnetron with Condenser Products Type ASG 202-40M storage capacitor rated at 0.002 uF and 40 kV.

** Recommended inductance range operation of SFD-315 magnetron with Condenser Products Type ASG 202-40M storage capacitor rated at 0.002 uF and 40 kV

4. Extension of Pre-Heat Time - A minimum of ten minutes was required to pre-heat the filament of the SFD-315 magnetron prior to the start of RF pulse operation; it took three minutes to pre-heat the filament of the BL-M006 magnetron. Time delay relay K1, which is located behind Transmitter-Receiver Control Panel (FIG. 2), was originally adjusted to accomodate the BL-M006 magnetron. For the NAFEC tests, this relay was readjusted to operate the indicator light after the maximum available time delay of five minutes. An additional five minutes was then allowed before manually energizing the voltage circuits. (A time-delay relay with a ten minute delay would be required as a permanent replacement for K1.) It was also found necessary to reset the filament-voltage control variac in order that pre-heat voltage would equal the operating voltage. A schematic diagram showing the location of the new filament transformer within the electrical circuit, the energy storage capacitor, and the tapped inductor added within modulator, is presented in Figure III-1.

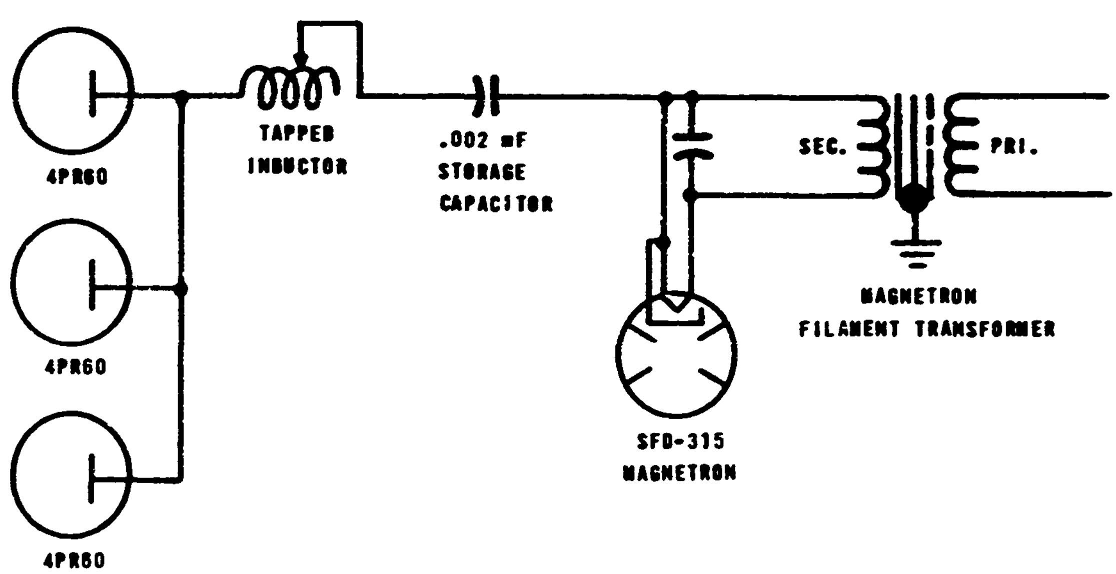

FIG. III-1 Schematic Diagram Showing Location of New Filament Transformer, Energy Storage Capacitor and Tapped Inductor within the Modulator Electrical Circuit.

APPENDIX IV

TEST OF AIL MODIFICATIONS FOR OPTIMUM OPERATION OF SFD-315 MAGNETRON

Effect of Series Inductor Adjustment on Radar Performance: The effect of adjusting the inductor in the modified modulator by connecting the slide arm to several different taps was explored in an effort to find the most satisfactory condition for operation of the SFD-315 magnetron, Serial No. G12E.

All of the nine taps provided on the inductance coil (see Figure 6) were selected, one at a time, and the transmitter's output pulse was observed, along with the panel instruments and video PPI display. Table IV-1 shows how radar performance was affected by tap changes.

Connection to some of the nine taps caused interference obscuring targets located within a radius of 600 feet from the radar antenna. Connection to all the taps caused some interference readily apparent on the PPI display (see Figure 7.) A connection to Tap No. 4 produced the least interference to the PPI display; however, even the best configuration resulted in excessive pulse duration and horizontal instability. The transmitter produced the least pulse duration when connection was made to Tap No. 3 on the coil. (Samples of the pulses from Channel B are presented for comparison with pulses from Channel A in Figure 8.)

Effect of Inductor Adjustment on other SFD-315 Magnetrons: Four other SFD-315 magnetrons, which had already performed during 4000 hours of life testing at the contractor's plant, were substituted for the SFD-315 magnetron, Serial G12E, and tests repeated with connections to different taps of the AIL inductor. Observed results were similar to results of the earlier tests with Serial G12E.

For each of the sample magnetrons tested, connection only to one tap on the inductor produced a noticeable reduction of the PPI interference. The least objectionable condition occurred when connection was made to a particular tap. The optimum tap was not more than one tap to either side of the tap found optimum for Serial G12E. The variations resulting from changing tap connections suggested that a useable video display might be obtained on the PPI by means of a fine adjustment to the series inductor. A slug tuned version of the original inductor was substituted for the contractor's model. Moving the slug slowly through the tuneable range of the experimental inductor reduced PPI interference, but the most favorable condition still failed to produce a PPI display comparable to the interference-free display in Channel A.

TABLE IV-1

EFFECTS OF INDUCTOR ON TRANSMITTER PERFORMANCE
SFD-315 MAGNETRON (SERIAL NO G12E)

Inductance Tap No.	External Inductance uH	Modulator Current mA	Pulse Duration ns	Modulator High Voltage kV	PPI Interference	Horizontal Jitter ns
1	1.25	19.40	Double pulse 27.0	14.25	Severe	5.0
2	3.5	17.0	Double pulse 28.0	15.7	Severe	10.0
3	6.5	16.50	29.0	16.7	Medium	10.0
4	9.8	15.50	30.0	17.6	Slight	10.0
5	13.4	15.10	31.0	18.5	Moderate	10.0
6	18.0	15.50	33.0	19.0	Slight Good Video	10.0
7	20.8	15.50	36.0	19.4	Moderate Fair Video	10.0
8	23.0	15.20	36.0	19.8	Severe	10.0
9	27.0	15.50	38.0	20.2	Medium	10.0

NOTE: Magnetron current was maintained at a constant level of 4.0 milliamperes throughout these tests in compliance with manufacturer's recommendations.

Effect of Modulator Storage Capacitance on Radar Performance: Other capacitors ranging in normal values from 0.005 uF to 0.004 uF were substituted for the 0.002 uF (introduced by AIL). Along with the adjustable series inductor, each of the capacitors were of different manufacture and appeared to possess different levels of internal impedance. No evidence of interference was observed on the PPI as these capacitors were tried in the modulator without the series inductor. However, pulse duration was found to vary considerably with each component. (See Table IV-2.) The shortest pulse obtained was 29 ns when Serial G12E was operated. This pulse duration was acquired with a 0.002 uF capacitor having an estimated value of internal inductance higher than that introduced by the AIL modification. (Figure 8.)

TABLE IV-2

PERFORMANCE OF SFD-315 MAGNETRON, SERIAL G12E. WITH VARIOUS STORAGE CAPACITORS

Nominal Capacitance uF	Manufacturer	Estimate Value of inductance in capacitor, uH	Modulator Current mA	Modulator HV. kV	Output Pulse ns	Average Power W
.002	Condenser Products	3.5	22.0	17.5	38.0	8.25
.002	Plastic Capacitor Corp.	14.0 (preempted from an SFD Laboratory mod.	21.5	16.5	29.0	9.0
.002 in series with .002	Condenser Prod. Plastic Capacitor Corp.	Estimated Total 10.0	16.4	20.0	29.5	16.0
.002 in parallel with 0.002	Condenser Prod. Plastic Capacitor Corp.	Estimated Total 16.0	21.5	16.75	30.0 (unstable)	9.0
.001 with inductor in series	Chicago Condenser Corp.	20-22 or greater	19.5	16.0	double pulses 30.0 ns 50.0 ns separation	10.0

NOTE: For these tests magnetron current was maintained at 4.0 mA.